

3. MEASUREMENT PROCEDURE

The calibration, system verification, and setup procedures described here were performed in each cell every morning before measurements began. Measurements were made during the daytime from approximately 8 AM to 5 PM. Before calibration began, the transmitter and receiver equipment were warmed up for one-half hour. The rubidium frequency standards were warmed up for at least 24 hours prior to calibration. The output power of the transmitter into a 50-ohm load was measured and recorded using a directional coupler and a power meter. Three primary calibration procedures were performed: frequency calibration, amplitude calibration, and absolute time calibration.

The frequency calibration procedure consisted of tuning the rubidium frequency standard located in the receiver so that its frequency matched that of the rubidium frequency standard located in the transmitter. This was accomplished by connecting the 5-MHz outputs of each frequency standard to a gain/phase meter and adjusting the frequency of the receiver's frequency standard to minimize the change in the phase difference over time between the two frequency standards. Frequency calibration was performed and highly stable rubidium frequency standards were used for three primary reasons. First, it was necessary to ensure that the in-phase and quadrature phase components for an individual impulse response did not rotate appreciably during data collection. Secondly, the sampling clock had to be accurate enough to ensure that the correct number of samples were taken within the 511-bit PN code word. If this condition is not met, the correlation noise floor increases, thereby decreasing the interval of discrimination (ID). The ID is the amplitude difference between the correlation peak and the peak of the noise in the power delay profile (PDP). The PDP is the magnitude squared of the measured complex impulse response. Finally, the absolute time capability required that the PN code generator in the transmitter and divide-by-511 board in the receiver remained synchronized as closely as possible for the entire duration of the measurements. Therefore, the rubidium frequency standards were used to clock both the PN code generator and the divide-by-511 board.

The second type of system calibration that was performed was a receiver amplitude calibration. This entailed connecting the transmitter directly to the receiver via a coaxial cable, with a variable attenuator inserted between the transmitter and receiver to control the amplitude of the signal input into the receiver. A complete amplitude calibration was performed after configuration of the measurement system before the actual measurements commenced. The complete amplitude calibration provided a series of PDPs at varying RF input power levels to the receiver for both receiver channels. The RF input power was decreased in 10-dB steps from the receiver's 0.5-dB compression point until the signal-to-noise ratio was so low that no PDP could be obtained.

An example of these calibration PDPs for a high-level input signal into the receiver (-48 dBm) is shown in Figure 3.1. From this PDP, the ID is seen to be approximately 51 dB. This approaches the theoretical limit of a 9-bit PN code generator given by $20 \cdot \log_{10} (2^n - 1) \approx 54$ dB where $n = 9$. From the calibration PDPs, it is noted that as the RF input power into the receiver decreases to roughly -60 dBm, the ID does not decrease. As the RF input power into the receiver decreases below -60 dBm, the ID decreases due to system noise. Processing gain is the difference between the output and input signal-to-noise ratios of a system [1]. The processing gain from a

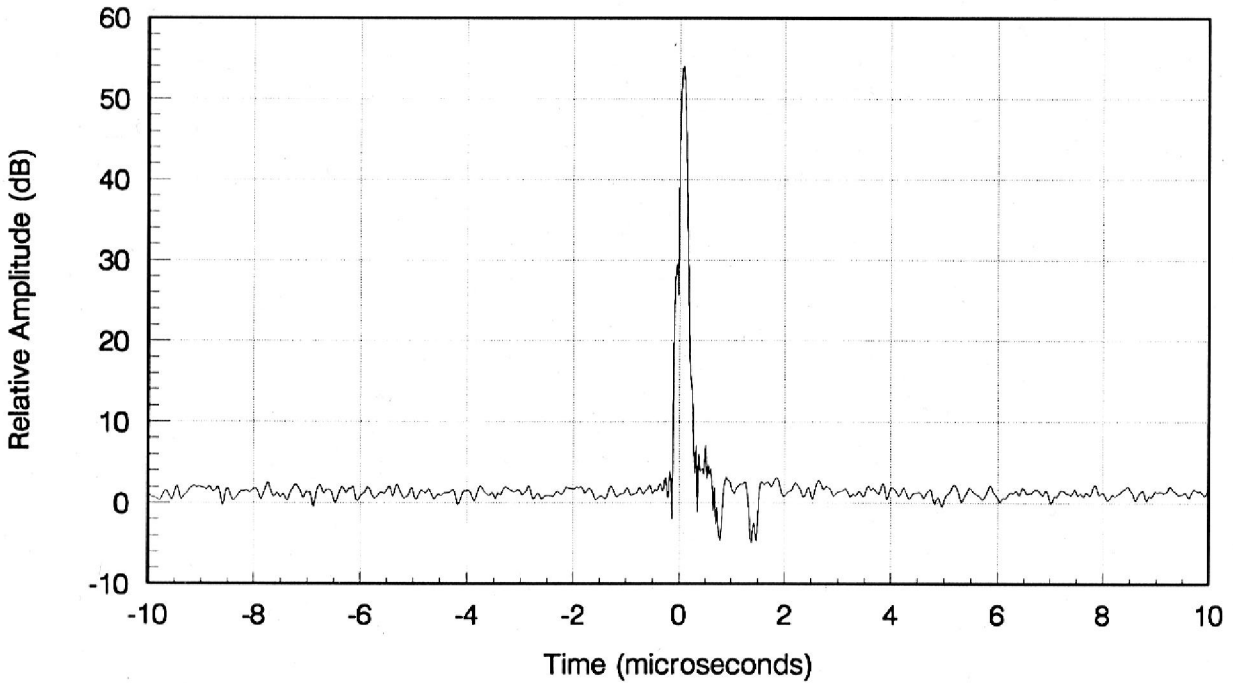


Figure 3.1. Example calibration power delay profile.

9-bit PN code generator is given as $10 \cdot \log_{10} (2^n - 1) \approx 27$ dB. This means that when the RF input power into the receiver is equal to the system noise of the receiver, the correlation peak will be 30 dB above the average noise level. This occurs when the RF input power is approximately -91 dBm. The presence of multipath even further reduces the ID.

The complete amplitude calibration is important since it allows verification of the proper operation of the measurement system, provides a relationship between the received signal power and the PDP, and allows approximate determination of the receiver noise figure from the PDP.

Every morning before measurements were made, an abbreviated amplitude calibration was performed. This procedure was identical to the complete amplitude calibration procedure except that the RF input power to the receiver was limited to one high and one low level. The PDPs obtained using these input power levels into the receiver were then compared to the corresponding PDPs generated in the complete calibration procedure. The results of this comparison showed whether the measurement system was operating properly.

The absolute time calibration was then performed. This procedure required a reset cable to be connected between the transmitter and receiver. A single switch then reset both the PN code generator in the transmitter and the divide-by-511 board in the receiver simultaneously. This ensured that the PN code and the external trigger pulse to the digital oscilloscope were synchronized within a few nanoseconds. The reset cable was then disconnected. With the transmitter still connected to the receiver via the coaxial cable and attenuator, data were captured

at a high-level RF input signal into the receiver. The PDP was obtained and the time that the peak of the PDP occurred was recorded. If there was no delay through the transmitter and receiver systems and the cable connecting the two, the peak of the PDP would occur at time zero. Due to delays through the filters and other components in the transmitter and receiver, however, the peak received signal occurred at about 300 ns.

After all of the calibration procedures were completed, the radio frequency spectrum was observed to determine the potential interfering signals in or near the measurement frequency band. The transmitter was disconnected and turned off while the receiver inputs were connected to the receive antennas. The antennas were mounted on the top of the telescoping mast for the rural sites and on top of the building in the urban high-rise cell. The receiver spectrum analyzers were set up in sweep mode to observe and display frequencies from 1850 to 1990 MHz. Interfering signals at several different frequencies were seen within the band in all of the cells. The center frequency of the measurement system was set such that any interference from or to existing services would be avoided.

An over-the-air test, which was primarily qualitative in nature, was then performed to test the proper functioning of the entire transmitter/receiver measurement system including the antennas and antenna feed cables. For this test, the transmitter was separated from the receiver by approximately 0.15 km. The transmitter was turned on and the received signals on both channels were checked for proper frequency and amplitude. Data were captured for both channels and the corresponding PDPs were compared to expected results to determine if the entire system was operating properly. The transmitter was kept operating while the rest of the setup procedures were performed and was not turned off until the measurements in that cell were completed for the day.

The transmitter van was moved to the beginning of the first route selected for measurement within the cell. The data acquisition and control software was activated at the receiver to prepare the measurement system for data collection. First, under computer control, the receiver hardware was initialized. Based upon the received signal levels, the amplitude sensitivity of both channels of the digital oscilloscope was automatically set by an autoscaling procedure. The sensitivity of each channel was set independently. The system operator had the option of overriding the automatic amplitude sensitivity settings and entering those desired. The system operator was then prompted for information to be stored in the data file header. This information included the cell number and description; the route number within the cell; and the transmit antenna type, polarization, and height.

After these setup procedures, the data acquisition was initiated and the transmitter van began travelling along the selected route. A rapid succession of 10 PDPs was taken at intervals of approximately 0.7 s as the transmitter van was moving. Within this succession of PDPs a time interval of 255.5 μ s (5 times the PN code word duration) was used between the beginning of one impulse and the beginning of the next. Spatial distance between each PDP within the succession of 10 ranged from approximately 0.17 to 0.63 m. The spatial distance between each succession of 10 PDPs ranged from 4.66 to 17.26 m. When the transmitter had to stop along the measurement routes, the data collection was suspended. The control software monitored signal levels on both channels and if either signal level was too low or too high for adequate digitization,

an alarm would sound and the corresponding data on both channels would not be recorded. If the signal levels were persistently too low or too high, the measurement van was stopped and the autoscale procedure was executed again before restarting data acquisition. Data of appropriate signal level were stored on the computer hard disk. Periodically, while data were not being collected, the previously recorded data would be spot checked by looking at randomly chosen PDPs. After all of the data had been acquired for the day, the data were checked by looking at selected PDPs taken that day. Assured that the data were sound, the data were backed up onto optical disk.